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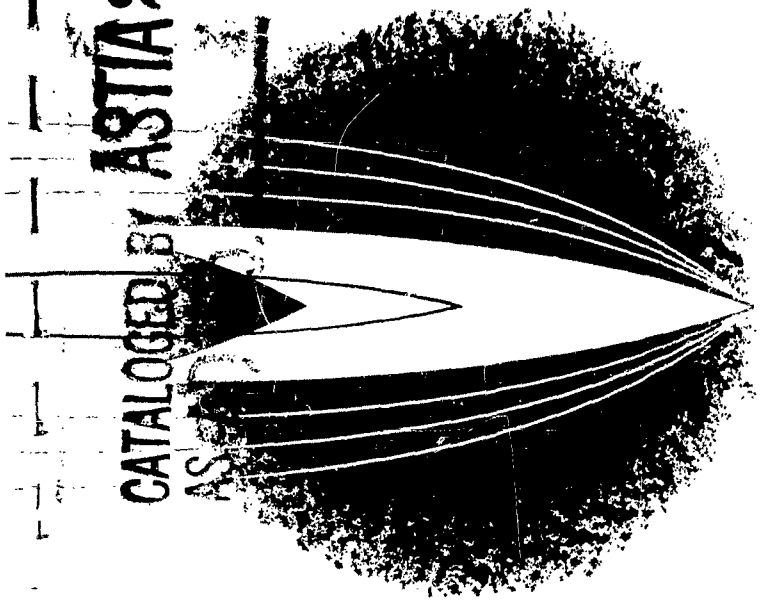

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STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

Contract DA-04-495-ORD-3069

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Structural Materials Division

Aerojet-General CORPORATION
AZUSA, CALIFORNIA SACRAMENTO, CALIFORNIA
THE GENERAL TIRE
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

20 October 1961

Report No. 0414-01-4
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INVESTIGATION OF STRESS-CORROSION CRACKING OF HIGH-STRENGTH ALLOYS

Contract DA-04-495-ORD-3069

Written by:

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No. of Pages: 9

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Period Covered:

1 July through 30 September 1961

AEROJET-GENERAL CORPORATION
Azusa, California

CONTENTS

CONTRACT FULFILLMENT STATEMENT

This is the fourth in a series of quarterly progress reports submitted in partial fulfillment of the contract.

I. OBJECTIVES

The objectives of this program include the study of the susceptibility to environmental stress-corrosion cracking of six candidate high-strength alloys for solid-propellant rocket-motor cases. The environmental parameters consist of the atmospheres to which the rocket-motor cases are exposed during manufacture, testing, and long-term storage.

Also included is a study of the effect of material parameters, such as composition, strength level, welding, microstructure, surface conditions, etc., on the stress-corrosion process.

The final phase of this program involves devising and evaluating techniques for preventing the stress-corrosion cracking of rocket-motor case materials.

II. SUMMARY

The accumulation of environmental stress-corrosion test data on the bent-beam and the U-bend test specimens is continuing. Bent-beam specimens selected from the high-strength groups of all the alloys except Vascojet 1000 have undergone 51 days of testing in the more aggressive environments without failure. U-bend specimens have undergone 100 days of environmental testing. Based upon the data collected to date, the Vascojet 1000 alloy steel is the least resistant to stress-corrosion cracking. Preparations are being made for the testing of welded specimens and for testing of all the alloys in a solid-propellant environment.

III. WORK PROGRESS

A. INTRODUCTION

In July 1961, a technical conference was held at Aerojet-General Corporation, Azusa, California, to discuss the progress of this program and to

outline the future work. In attendance were Mr. H. Rosenthal of Frankford Arsenal, technical monitor of the program, Mr. W. D. Ruble of Mellon Institute, where a parallel study of the stress-corrosion behavior of the same alloys in synthetic environments is being conducted, and Messrs. R. B. Robinson and R. J. Uzdarwin of Aerojet. The agenda of the conference included the presentation and discussion of the progress made by both Aerojet and Mellon during the first year of the investigation. Following this, the programs for the second year were presented and discussed. The proposed effort for Aerojet during the second year of the program is outlined in the section of this report entitled, "Future Work."

The first quarter of the second year's effort is completed, and during this period the completion of the screening of the PH 15-7Mo stainless steel was accomplished, the extended environmental testing of all six alloys was initiated, and preparations for the testing of welded specimens and solid propellant environments were begun.

B. BENT-BEAM TEST SPECIMENS

A summary of all the environmental bent-beam stress-corrosion test data compiled to date is given in Table 1. These results reflect both completed tests and tests that are currently in progress. Bent-beam specimens, stressed to 75% of the 0.2% offset yield strength, of Ladish D6AC, Type 300M, and Vascojet 1000 alloy steels, AM 355 and PH 15-7Mo stainless steels, and B120VCA titanium alloy were tested in air, distilled water, tap water, 0.25% sodium dichromate solution, 1% marquench salt solution, 3% sodium chloride solution, trichloroethylene, cosmoline, and 4% soluble oil solution. Tests currently in progress include bent-beam specimens of Ladish D6AC alloy steel and PH 15-7Mo stainless steel in high humidity, and of Ladish D6AC and Type 300M alloy steels, AM 355 and PH 15-7Mo stainless steels, and B120VCA titanium alloy in tap water and distilled water. Previous environmental stress-corrosion tests in tap water and distilled water were terminated after 21 days. The only alloy to fail in these environments within 21 days was Vascojet 1000 steel. It is hoped that the extended tests currently in progress will indicate relative stress-corrosion susceptibility of the other alloys. The test specimens used were selected from the high-strength groups of each alloy. No failures were observed after 51 days of testing.

Bent-beam tests of welded specimens in selected environments are being prepared. At the present time, only specimens of Ladish D6AC, Type 300M, and Vascojet 1000 alloy steels and B120VCA titanium alloy are being considered. In addition, arrangements are being made to coat specimens of each alloy with solid propellant for environmental bent-beam stress-corrosion tests at ambient and elevated temperatures.

C. U-BEND TEST SPECIMENS

A summary of all the environmental U-bend stress-corrosion test data compiled to date is given in Table 2. All the U-bend tests are currently in progress, and include specimens of Ladish D6AC, Type 300M, and Vascojet 1000 alloy steels in distilled water, tap water, 0.25% sodium dichromate solution, 1% marquench salt solution, 3% sodium chloride solution, trichloroethylene, cosmoline, and 4% soluble oil solution.

The test results reflect the cumulative effects of 100 days of testing. Failures were observed with each alloy in the environments of distilled water, tap water, salt water, and trichloroethylene. It is significant to note that, in each case, the Vascojet 1000 alloy showed the greatest susceptibility to stress-corrosion failure, while the Ladish D6AC alloy was the most resistant to stress-corrosion cracking.

D. DISCUSSION

Examination of the test data will show that the only bent-beam specimens to fail in room temperature environments ($75^{\circ}F$) were those of Vascojet 1000 alloy steel. However, in the high humidity environment (at $190^{\circ}F \pm 10^{\circ}F$), bent-beam specimens of Ladish D6AC alloy steel failed within two weeks. Other Ladish D6AC specimens tempered to the same strength level and stressed in the same manner have not failed after more than seven weeks of exposure to room temperature environments. These data indicate that temperature, as well as environment, has a very pronounced effect upon the time until stress-corrosion failure occurs.

Upon close examination of the failed specimens, some interesting observations were made. First, with the bent-beam specimens, the Vascojet 1000 specimens failed straight across, the fracture being perpendicular to the edges and to the sides. The Ladish D6AC specimens failed irregularly in both directions. Secondly, with the U-bend specimens, the Vascojet 1000 specimens failed in a manner similar to the bent beam specimens, and in no case did failure, either stress-corrosion or mechanical, occur in the plastically deformed region. The Ladish D6AC specimens again failed irregularly in both directions, with both stress-corrosion and mechanical failure occurring in the plastically deformed region in nearly every case. Irregular failure also occurred with the Type 300M test specimens. However, the stress-corrosion appeared to initiate in the elastic section, which propagated mechanically through the plastically deformed region. These different types of failures appear to indicate specific trends, but further study along these lines is needed in order to draw any conclusions. It is intended to include within the scope of this program an investigation of the mode of stress-corrosion failure of the various alloys. Electron microscopy and other specialized metallographic techniques will be employed to pursue this study.

IV. FUTURE WORK

The following outline was established for the second year of the program:

A. Complete the screening tests of the PH 15-7Mo stainless steel.

B. Extend exposure of all six alloys at selected levels for periods ranging from three to six months.

C. Fabricate and test weld specimens from those materials that exhibit the best resistance to stress-corrosion cracking.

D. Investigate protective systems, including coatings and additives, such as chromates, nitrites, etc., to selected environments.

E. Conduct extended exposure tests employing the most resistant materials strengthwise with solid propellant coatings. Environment is to be confined to elevated temperatures, ambient temperatures, protective coating on compressive side, and no coating on compressive side.

F. Other supplementary investigations per mutual agreement of Frankford Arsenal and Aerojet.

TABLE 1

BENT-BEAM STRESS-CORROSION TEST DATA*

ENVIRONMENT

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	Air		Distilled Water		Tap Water		0.25% $Na_2Cr_2O_7$ Soln.		1% Marquench Salt Soln.		3% Nacl Soln.		Trichloroethylene		Cosmoline		1% Soluble Oil Soln.		High Humidity	
		No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)
Ladish D6AC	198.0	3	NF-28**	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	MF-115
	223.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	NF-115
																				1	57.0
	235.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	61.7
		3	NF-51	6	NF-51	6	NF-51	3	NF-51	3	NF-51	3	NF-51	3	NF-51	3	NF-51	3	NF-51	1	23.0
																				1	23.2
	252.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	26.7
		3	NF-51	6	NF-51	6	NF-51	3	NF-51	3	NF-51	3	NF-51	3	NF-51	3	NF-51	3	NF-51	1	5.7
																				1	7.0
																				1	14.2
Type 300M	196.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
	213.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
	233.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
				3	NF-51	3	NF-51														
Vasco-Jet 1000	194.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
	212.0	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
				1	7.6	1	13.7					1	6.9								
	238.0	3	NF-28	1	7.8	1	14.7	3	NF-21	3	NF-21	1	10.0	3	NF-21	3	NF-21	3	NF-21	-	-
				1	7.9	1	15.7					1	10.1								
				1	1.8	1	2.7					1	1.2								
	242.0	3	NF-28	1	3.2	1	8.8	3	NF-21	3	NF-21	1	1.7	3	NF-21	3	NF-21	3	NF-21	-	-
				1	4.3	1	9.7					1	6.7								
AM355	199.0(T)***	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	3	NF-49	-	-
	250.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
				3	NF-51	3	NF-51														
	278.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
				3	NF-51	3	NF-51														

* Stressed to 75% of the 0.2% offset yield strength.
** NF-28 = No failure in 28 days.
*** L = Longitudinal, T = Transverse

TABLE 1 (cont.)

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	Air		Distilled Water		Tap Water		0.25% $Na_2Cr_2O_7$ Soln.		1% Harquench Salt Soln.		3% Nacl Soln.		Trichloroethylene		Cosmoline		4% Soluble Oil Soln.		High Humidity	
		No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)
PH 15 - 7 Mo	200.0	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56
	225.0	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56
	237.0	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56	3	NF-56
B120VCA Titanium	138.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
	140.0(T)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	NF-21	2	NF-21	3	NF-21	3	NF-21	-	-
												1	0.00	1	3.4						
	146.0(T)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	1	0.03								
												3	NF-21	2	NF-21	3	NF-21	3	NF-21	-	-
	149.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21			1	0.9						
	158.0(L)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
	166.0(T)	3	NF-28	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	3	NF-21	-	-
				3	NF-51	3	NF-51														

Table 1
Sheet 2 of 2

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TABLE 2

U-BEND STRESS-CORROSION TEST DATA

ENVIRONMENT

Alloy	Yield Strength 0.2% Offset psi x 10^{-3}	Distilled Water		Tap Water		0.25% $Na_2Cr_2O_7$ Soln.		1% Marquench Salt Soln.		3% Nacl Soln.		Trichloroethylene		Comsoline		1% Soluble Oil Soln.	
		No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)	No. Of Specimens	Time To Failure (Days)
Ladish D6AC	198.0	2	NF-100*	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100
	223.0	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100
	235.0	1	20.2	1	NF-100	1	NF-100	2	NF-100	1	NF-100	2	NF-100	2	NF-100	2	NF-100
		1	32.9	1	33.3					1	62.4						
	252.0	1	18.4	1	28.9	2	NF-100	1	NF-100	1	18.5	1	NF-100	2	NF-100	2	NF-100
		1	22.4	1	39.9							1	46.9				
Type 300M	196.0	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100	2	NF-100
	213.0	1	18.4	2	NF-100	2	NF-100	2	NF-100	1	11.3	1	49.9	2	NF-100	2	NF-100
		1	34.9							1	40.9	1	56.1				
	233.0	1	14.9	1	22.4	2	NF-100	2	NF-100	1	11.3	2	NF-100	2	NF-100	2	NF-100
		1	34.9	1	29.1					1	26.3						
Vasco-Jet 1000	194.0	2	NF-100	2	NF-100	2	NF-100	2	NF-100	1	NF-100	2	NF-100	2	NF-100	2	NF-100
										1	49.9						
	212.0	1	NF-100	1	60.4	2	NF-100	2	NF-100	1	13.7	2	NF-100	2	NF-100	2	NF-100
		1	14.7	1	69.4					1	53.3						
	240.0	1	4.4	1	7.4	2	NF-100	2	NF-100	1	4.3	1	46.9	2	NF-100	2	NF-100
		1	11.4	1	19.5					1	6.8	1	46.9				

* NF-100 = No failure in 100 days.

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